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13. ABSTRACT (Maximum 200 words)

A workshop was held bringing together researchers in the specialties that address modeling, analysis and control of discrete events systems. As a result a set of important research problems for the development of an overall theory were posed.

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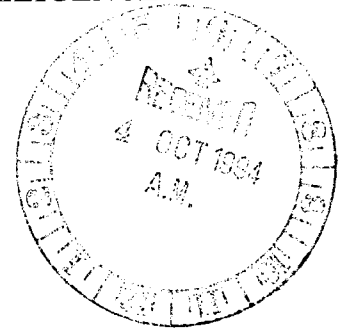
SPECIAL FINAL TECHNICAL REPORT

on

A WORKSHOP ON THE CONTROL
OF
DISCRETE EVENT SYSTEMS

Grant Number F49620-94-1-0089

Submitted by:

Alexander H. Levis
Principal Investigator

Report #: GMU/C3I-154-IR

September, 1994

1. OBJECTIVES

The purpose of the workshop was to bring together for two days of presentations and discussions leading researchers in the various specialties that address the modeling, analysis, and control of discrete event systems. It was recognized that while there has been substantial progress in the individual specialties, such as finite state Markov chains, Petri Nets, queuing theory, and perturbation analysis (DEDS), very little progress has been made in developing a mathematical framework that subsumes the current approaches and results and, most importantly, opens the way for new insights and new, fundamental results. Clearly, the increasing incorporation of computers and logic models as integrated components of many man-made systems makes discrete event system modeling a necessity.

The increasing scale of many of our man-made systems mandates asynchronous and concurrent operations to maintain acceptable delays and use resources efficiently. Typical examples include global communication systems (e.g., Internet); flexible manufacturing plants that must exhibit high level of productivity; many operational systems such as the distributed decision making system representing the theater JFACC/AOC/Wing/Squadron chain in the planning and execution of theater air operations; air traffic control centers and their integration into a larger system to handle traffic flow management (TFM), etc.

The technical presentations in the workshop were of two types: talks giving a description of the current advances in specific disciplines and characterizing the major theoretical and computational challenges, and talks addressing specific application domains and the theoretical challenges they pose.

The outcome of the workshop was a set of informal findings regarding the state of the art, and a set of research problems that seem promising in terms of the development of an overall theory of discrete event systems, a theory that leads to the design of better systems and procedures.

2. THE WORKSHOP PAPERS AND PRESENTATIONS

The following presentations were made at the workshop. Most were supported by original papers writen for the occasion; several were original presentations in vu-graph form supported by related papers.

1. Engineering Design and Soft Optimization,
   Yu-Chi Ho, Harvard University, Cambridge MA.

   In this talk we take the viewpoint that the main goal of engineering design is "to do better", and if possible, "to find the best" . However, in many real world problems "the best" is only a theoretical ideal that often is unattainable or not cost effective. Instead, if we accept a more rnodest goal of "being good enough" or "soft optimization", then much can be achieved even for problems currently considered to be beyond reach. Furtherrnore, asking such a softer question leads to the possibility of quantitatively analyzing heuristic or rule-of-thurnb methods of design.

2. Joint Task Force Southwest Asia,
   Major General George B. Harrison, Commander, Air Force Operational Test And Evaluation Center, Kirtland Air Force Base, Albuquerque NM.

This is a presentation, supported by vu-graphs, in which the mission, organization, operations and forces of a Joint Forces Air Component Commander (JFACC) are described. The concepts are illustrated by describing the actual forces in Southwest Asia, as they were deployed in the summer of 1993.

3. <u>An Integrated Methodology for the Modeling, Scheduling and Control of Flexible Automation,</u>
Wayne J. Davis, Duane Setterdahl, Joseph Macro, Vikctor Izokaitis and Brad Bauman, University of Illinois at Urbana-Champaign, Urbana Illinois.

This paper first establishes the need to develop a comprehensive framework for the integrated modeling, scheduling and control of flexible manufacturing systems (FMSs) . To model flexible automation, it is argued that simulation tools must explicitly consider the controller interactions which coordinate the flows of both jobs and supporting production resources. In addition, the simulation tools must permit direct consideration of the detailed process plans for the variety of parts to be manufactured within a FMS. To effectively manage FMSs, it is then demonstrated that scheduling and control must be considered concurrently in real-time. Further, the complexity of the modern FMS requires that the integrated scheduling and control function be distributed among several coordinators within the FMS. The simulation must also recognize this distribution of the scheduling and control functions within the model to accurately project the performance of the FMS operating under a specified scheduling/control strategy. The second part of the paper presents several research developments pertaining to the modeling, scheduling and control of flexible automation including: a Recursive, Object-Oriented Coordination Hierarchy for the integrated distribution of scheduling and control; a Hierarchical Object-Oriented Programmable Logic Simulator for the detailed modeling of FMSs; and a Hierarchical Subsystem Coordinator for implementing real-time scheduling and control. A discussion of on-going research in real-time, discrete-event simulation is also presented. A physical emulator for an FMS is discussed throughout the paper as a testbed for the proposed integrated development of the above algorithms. Finally, the future research plan and the educational program based upon the emulator are outlined.

4. <u>Petri Nets In Command and Control,</u>
Alexander H. Levis, George Mason University, Fairfax VA.

An introductory presentation on Colored Petri Nets and their use in the modeling, analysis, and design of architectures for command and control, and especially, the production of the Air tasking Order (ATO) was supported by a recently completed paper by Perdu, Spohnholtz, and Levis on the modeling of information pull in the Navy's Copernicus architecture. The Copernicus Architecture is being developed to make information from all sources available to the warfighter at sea. This information need not be pushed automatically to the Battle Group; there is too much data and a large fraction of it is not relevant to the mission. On the other hand, relevant information requested by the warfighter should be received in time. Since Information Pull is central to the Copernicus Architecture, a Colored Petri Net model has been developed to investigate different modes of Information Pull: (1) Simple Pull, where the response to a query contains only the answer to the query and (2) Enhanced Pull, where the response to the query contains not only the answer to the query but also updates generated since the previous query that are relevant to the warfighter's mission. The study focuses on the load on the TADIXS Communications network that connects the Battle Group to the CINC Command Complex ashore.

5. <u>Discrete Event Systems Computations Using a C/E Systems Toolbox,</u>
   Bruce H. Krogh, Toshihiko Niinomi, Jeffrey Oplinger, Carnegie Mellon University, Pittsburgh Pa.

   A presentation on the development of a MATLAB™ based toolbox that utilizes Binary Decision Diagrams to describe Condition/Event systems.

6. <u>Rapid Learning Techniques for Control and Optimization of Discrete Event Systems,</u>
   Christos G. Cassandras, University of Massachusetts, Amherst, MA.

   Stochastic timed automata are used as the mathematical framework to extract information from a single trajectory of a discrete event system; this is the rapid learning model.

7. <u>Lessons Learned About Modeling Discrete Event Systems,</u>
   Robert Tenney, Alphatech, Inc., Burlington MA.

   Stochastic Timed Attributed Petri Nets (STAPNs) are a general purpose representation of discrete event systems. To date, a great deal of literature has appeared relating to static analysis of a STAPN model, and concerning simulation of STAPNs. The field is poised for a tremendous leap forward into techniques for dynamic analysis of STAPN systems, including explicitly synthesis of estimation and control techniques for on-line monitoring and control of discrete event systems. Because of their structure, STAPNs are unlikely to yield the sarne types of solution as can be obtained for systems described by differential or difference equations. Nonetheless, the perturbation analysis algorithm provided here opens the door to a different class of design techniques, which can place the design of large, complex, discrete event systems on a more rigorous footing.

8. <u>Modeling and Design of Hybrid Control Systems.</u>
   Panos J. Antsaklis, Michael Lemmon, and James A. Stiver, University of Notre Dame, Notre Dame IN.

   Hybrid control systems contain two distinct types of systems, continuous state and discrete-state, which interact with each other. Their study is essential in designing sequential supervisory controllers for continuous-state systems, and it is central in designing control systems with a high degree of autonomy. After an introduction to intelligent autonomous control and its relation to hybrid control, models for the plant, controller, and interface are introduced. The interface contains memoryless mappings between the supervisor's symbolic domain and the plant's nonsymbolic state space. It is shown that a DES controller can be designed for the hybrid control system using extensions of logical DES theory. The simplicity and generality afforded by the assumed interface allows us to directly confront important system theoretic issues in the design of supervisory control systems; such as stability and determinism. The concept of (transition) stability is introduced to design valid discrete event system models. To handle the design of hybrid controllers for large systems, sufficient conditions for (transition) stability are written in terms of linear inequalities. Computationally efficient methods, such as the ellipsoid method, are then used in the design of the interface and the DES controller. In addition, these algorithms can be interpreted as on-line learning algorithms (inductive inference), which means that interface design can be performed as part of an on-line identification of the events used by the supervisor in controlling the plant.

9. <u>Robustness issues in Hybrid Systems,</u>
   Peter Ramadge, Princeton University, Princeton, NJ.

The presentation was based on recent papers and current work of the speaker and his colleagues. Contrasting examples of discreetly controlled continuous systems were presented; the timed automaton model was used. These examples exhibit what may be regarded as the two extremes of complexity of the closed-loop behavior: one is eventually periodic, the other is chaotic. The examples were derived from sampled deterministic flow models. In each case, a precise characterization of the closed loop behavior was given.

10. Manufacturing Applications for DEDS Techniques,
    James C. Malas, Materials Directorate, Wright Laboratory, Wright-Patterson AFB, Dayton, OH.

    A presentation, supported by vu-graphs and a plant visit, was given of current problems of interest to the Air Force in the materials area.

11. Making Genetic Algorithms Fly: A Lesson from the Wright Brothers,
    David E. Goldberg, University of Illinois at Urbana-Champaign, Urbana, IL.

    A tutorial presentation on genetic algorithms was given and current challenges were described. The presentation was supported by a set of vu-graphs.

12. Optimizing Performance Functions in Stochastic Systems,
    Stephen M. Robinson, Erica L. Plambeck, Bor-Ruey Fu, Rajan Suri, University of Wisconsin, Madison WI.

    A new method for optimizing performance functions in stochastic systems is proposed. These functions can include expected performance in static systems and steady-state performance in discrete-event dynamic systems. The method uses nonsmooth convex optimization, and it applies to systems in which the performance function is convex and in which subgradients of that function can be estimated (for example, by simulation). The method appears to overcome some limitations of stochastic approximation, which is often applied to such problems. We explain the method and give computational results for two classes of problems: tandem production lines with up to 50 machines, and stochastic PERT (Program Evaluation and Review Technique) problems with up to 70 nodes and 110 arcs.

13. Parallel Real-Time Multicriteria Mission Routing,
    Vincent A. Droddy, Jarnes Olsan, Gary B. Lamont, and Andrew J. Terzuoli, Air Force Institute of Technology, Wright-Patterson Air Force Base, Dayton, OH.

    Current systems for military aircraft route planning do not operate in even near-real time. The research has the ultimate goal of producing a parallel software system capable of autorouting a vehicle through a dynamic threat environment. Two major lines of research are reported here. In the first, a modified A* search used dynamic radar exposure evaluation to adapt to a changing threat environment. A complementary effort applies genetic algorithms to the problem. The fitness of proposed routes is evaluated using two criteria: distance traveled (related to fuel consumption) and exposure to radar detection. At each location, the probability of detection by radar is evaluated, using models of "bistatic" radar. That is, each of several radars has one broadcast antenna and a receive antenna for each of the radars. Primary development is being conducted on the Intel iPSC/860 Hypercube to allow study of the scalability of the algorithm. This problem is being approached with both deterministic and guided stochastic approaches. The deterministic algorithm is a modified best-first branch and bound algorithm, with a distributed "open" list and implicit "closed" list. The research seeks to evaluate the suitability of the algorithm for

a parallel architecture, and determination of its scalability. Also being studied is the suitability of the algorithm to other hardware architectures, particularly a mesh architecture. The guided stochastic research uses parallel a genetic algorithm which begins with a population of candidate routes. The population is spread across several semi-autonomous genetic algorithms, each with slightly different objective functions. Current software uses static weighting of the search criteria, but may be modified to permit dynamic weighting of search criteria as functions of space and time. Results so far indicate good results over a variety of criterion weighting. Research so far indicates the superiority, for this application, of a regular, square grid system over hexagonal grids or line-segment representation of terrain features.

14. <u>Pertubation</u> <u>Analysis</u> <u>for</u> <u>the</u> <u>Design</u> <u>of</u> <u>Flexible</u> <u>Manufacturing</u> <u>System</u> <u>Flow</u> <u>Controllers</u>, Michael Caramanis, George Liberopoulos, Boston University, Boston MA.

Dynamic allocation of stochastic capacity among competing activities in a just in time manufactunng environment is addressed by optimal flow control. Optimal policies are characterized by generally intractable Bellman equations. A near-optimal controller design technique is proposed. It provides an approximate numerical solution to the Bellman equation, a tight lower bound for the optimality gap of tractable, near-optimal controller designs, and a building block for improved, near-optimal controller designs that rely on the decomposition of a multiple part-type problem to smaller (two or three part-type) problems. Computational experience is reported for two and three part-type problems.

3. WORKSHOP PROCEEDINGS

A volume with copies of the papers and the vu-graph presentations was distributed to all attendees at the beginning of the workshop. Additional contributions were reproduced and distributed at the workshop itself. Furthermore, the remaining copies were made available to professionals who requested them. This volume should be considered as an Appendix to this letter report. All the papers contain lists of references; together they constitute a rudimentary bibliography for this research area.

4. ATTENDEES

A list of attendees and a booklet with brief biographical sketches of all participants was distributed at the workshop. It should be considered as another Appendix to this report.

5. MEETING

The workshop was held at the Wright-Patterson Air Force Base on February 24-25, 1994.

6. PERSONNEL

The Principal Investigator of this project was Prof. Alexander H. Levis; Mr. Lee Wagenhals was the research staff person who handled the organization and execution of the workshop.